

Report on Quadrupole and Dipole Sorting for the APS Booster Synchrotron

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ABSTRACT

This is a report of the implementation of dipole and quadrupole magnet sorting carried out for the injector synchrotron. The method used for implementing the sorting was developed by the author, see Koul¹ or Koul². The arrangement of the dipoles around the injector synchrotron, after sorting, reduced the $\delta x/\sqrt{\beta}$ by a factor of six. Whereas the arrangement of the quadrupoles around the injector synchrotron, after sorting, reduced $\delta\beta/\beta$ by approximately a factor of five.

Introduction

The APS injector synchrotron ring measures approximately 368 meters in circumference. The ring is designed to accelerate the positrons from the initial energy of 450 MeV to the final energy of about 7.5 GeV, at low beam loss. It has sixty-eight dipole magnets and eighty quadrupole magnets. The field tolerance limits on these magnets were given earlier from linearized error analysis, and reported in Koul³ or Teng⁴. These limits were further verified by simulations carried out using the computer program Elegant, see Koul⁵. The tolerance

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limit for dipoles was established at $\Delta B/B \sim 10^{-3}$, whereas for quadrupoles the quadrupole error tolerance was given at $\Delta B'/B' \sim 1.5 \times 10^{-3}$.

In the following we will first report on the sorting of the dipoles and then on the sorting of the quadrupoles.

Dipole Sorting:

The measured magnetic field data for the injector synchrotron dipoles was provided by the magnet measurement group. The data used in the sorting procedure is shown in the fourth column of Table 1. The sorting of the dipoles was carried out in four phases. In the first phase sixteen magnets were sorted. Random errors for the magnets were obtained by subtracting the mean of the error, obtained for the first twenty-one magnets measured, from the measured errors. The mean value of errors for the subsequent batches was obtained by using all the magnets measured, i.e., both previously sorted and the newly measured magnets. Figure 1 shows how this mean kept changing. To sort the subsequent batches, the new value of the random errors was used for the previously sorted magnets. This problem of changing mean error values rendered the sorting process less than ideal. However, the results of this sorting show that this technique is efficient even in such situations. The orbit distortion $\delta x/\sqrt{\beta}$ was reduced by a factor of six as compared to the orbit distortion one would have obtained if the magnets were not sorted. The list of the sorted magnets is given in Table 1. Position one corresponds to the dipole magnet B1C1B1, with succeeding dipoles following in the clockwise direction. The first column of the table gives the position assigned to a dipole, named in column two. The third column gives the corresponding position of the dipole magnet in the injector synchrotron. Finally the fourth column gives the measured error value used for final sorting.

Quadrupole Sorting

The quadrupoles were also sorted in batches. However, the mean value of the error from the first batch to the last batch changed by an order of magnitude, see figure 2. Such a large change in the mean value made the previous sorted batch very ineffective in reducing the amplification factor of the succeeding sort.

In view of this, it was decided that the final sort must be carried out on the remaining 40 quadrupoles simultaneously. This helped and $\delta\beta/\beta$ was reduced by a factor of 4.6 over a random placement. The final placement of the sorted quadrupoles is given in Table 2. As in the case of first table, the first column gives the position assigned to the quadrupole named in column two, the third column gives the corresponding position in the injector synchrotron, and the last column gives the measured error value of the quadrupole used in sorting.

References:

1. Rabinder Kumar Koul, AIP Conference Proceedings No 292; Particles and Fields Series 54; Stability of Particle Motion in Storage Rings, 1992.
2. R. K. Koul, Fredrick Lopez and Fredrick E. Mills, Optimal Magnet Sorting - Procedure and Application to the APS Injector Synchrotron, Proc. of the 1993 IEEE Particle Accelerator Conference, held in Washington, DC, May 1993.
3. R. K. Koul and F. E. Mills, Linearized Error Analysis for an Accelerator and Application to the APS Injector Synchrotron, LS-230, Dec. 1993.
4. L. Teng, private communication.
5. R. K. Koul, to be published.

Table 1: SORTED BOOSTER DIPOLES:

Assigned Position	Dipole	Booster Position	Random Error
	Name	Name	Value
POSITION[1]	BDP017	B1C1B1	0.0000839130434782607
POSITION[2]	BDP009	B1C2B1	0.000003913043478260647
POSITION[3]	BDP010	B1C2B2	0.0003139130434782607
POSITION[4]	BDP014	B1C3B1	0.0001539130434782607
POSITION[5]	BDP033	B1C3B2	0.0003039130434782606
POSITION[6]	BDP035	B1C4B1	0.0003939130434782606
POSITION[7]	BDP031	B1C4B2	0.0005839130434782608
POSITION[8]	BDP008	B1C5B1	-0.00002608695652173933
POSITION[9]	BDP013	B1C5B2	-0.0003760869565217392
POSITION[10]	BDP004	B1C6B1	0.0003839130434782607
POSITION[11]	BDP012	B1C6B2	0.0001839130434782607
POSITION[12]	BDP021	B1C7B1	-0.0001560869565217393
POSITION[13]	BDP029	B1C7B2	0.00007391304347826067
POSITION[14]	BDP019	B1C8B1	0.0003539130434782606
POSITION[15]	BDP022	B1C8B2	0.00003391304347826072
POSITION[16]	BDP026	B1C9B1	0.0002039130434782606
POSITION[17]	BDP015	B1C9B2	0.0003839130434782607
POSITION[18]	BDP024	B2C0B1	0.0000439130434782607
POSITION[19]	BDP027	B2C0B2	0.0001739130434782607
POSITION[20]	BDP028	B2C1B1	0.0003839130434782607
POSITION[21]	BDP018	B2C1B2	-0.0001960869565217393
POSITION[22]	BDP030	B2C2B1	0.0003639130434782607
POSITION[23]	BDP034	B2C2B2	0.0000439130434782607

Assigned Position	Dipole Name	Booster Position Name	Random Error
			Value
POSITION[24]	BDP051	B2C3B1	0.0004239130434782607
POSITION[25]	BDP020	B2C3B2	0.0002039130434782606
POSITION[26]	BDP023	B2C4B1	0.00005391304347826065
POSITION[27]	BDP032	B2C4B2	0.00007391304347826067
POSITION[28]	BDP036	B2C5B1	0.0001739130434782607
POSITION[29]	BDP025	B2C5B2	0.0001039130434782606
POSITION[30]	BDP011	B2C6B1	0.0001639130434782607
POSITION[31]	BDP016	B2C6B2	0.0001839130434782607
POSITION[32]	BDP059	B2C7B1	-0.0007260869565217393
POSITION[33]	BDP045	B2C7B2	0.0004039130434782608
POSITION[34]	BDP054	B2C8B2	0.0002139130434782607
POSITION[35]	BDP062	B3C1B1	-0.0005560869565217395
POSITION[36]	BDP043	B3C2B1	0.000003913043478260647
POSITION[37]	BDP047	B3C2B2	0.00007391304347826067
POSITION[38]	BDP070	B3C3B1	-0.0004560869565217395
POSITION[39]	BDP007	B3C3B2	-0.000936086956521739
POSITION[40]	BDP040	B3C4B1	0.0002039130434782607
POSITION[41]	BDP060	B3C4B2	-0.0005360869565217394
POSITION[42]	BDP053	B3C5B1	0.0001139130434782607
POSITION[43]	BDP071	B3C5B2	-0.0007560869565217394
POSITION[44]	BDP041	B3C6B1	0.0003539130434782607
POSITION[45]	BDP068	B3C6B2	-0.0005560869565217395
POSITION[46]	BDP050	B3C7B1	0.0002239130434782607

Assigned Position	Dipole Name	Booster Position Name	Random Error Value
POSITION[47]	BDP042	B3C7B2	0.0001239130434782607
POSITION[48]	BDP039	B3C8B1	0.0000139130434782607
POSITION[49]	BDP058	B3C8B2	-0.0006760869565217394
POSITION[50]	BDP055	B3C9B1	-0.0003260869565217392
POSITION[51]	BDP064	B3C9B2	-0.0003360869565217394
POSITION[52]	BDP049	B4C0B1	0.0002639130434782607
POSITION[53]	BDP005	B4C0B2	0.0005639130434782608
POSITION[54]	BDP038	B4C1B1	-0.0000760869565217394
POSITION[55]	BDP057	B4C1B2	-0.0001660869565217393
POSITION[56]	BDP056	B4C2B1	-0.0001060869565217393
POSITION[57]	BDP044	B4C2B2	0.0003139130434782607
POSITION[58]	BDP067	B4C3B1	-0.0001060869565217393
POSITION[59]	BDP066	B4C3B2	-0.0003660869565217393
POSITION[60]	BDP048	B4C4B1	0.0001939130434782607
POSITION[61]	BDP052	B4C4B2	-0.0001660869565217393
POSITION[62]	BDP006	B4C5B1	-0.000826086956521739
POSITION[63]	BDP037	B4C5B2	0.0001339130434782607
POSITION[64]	BDP065	B4C6B1	-0.00005608695652173932
POSITION[65]	BDP061	B4C6B2	-0.0004360869565217394
POSITION[66]	BDP069	B4C7B1	-0.0005560869565217395
POSITION[67]	BDP046	B4C7B2	0.0002239130434782607
POSITION[68]	BDP063	B4C8B2	-0.0003360869565217394

MEAN VALUE AS FUNCTION
OF BATCH NUMBER

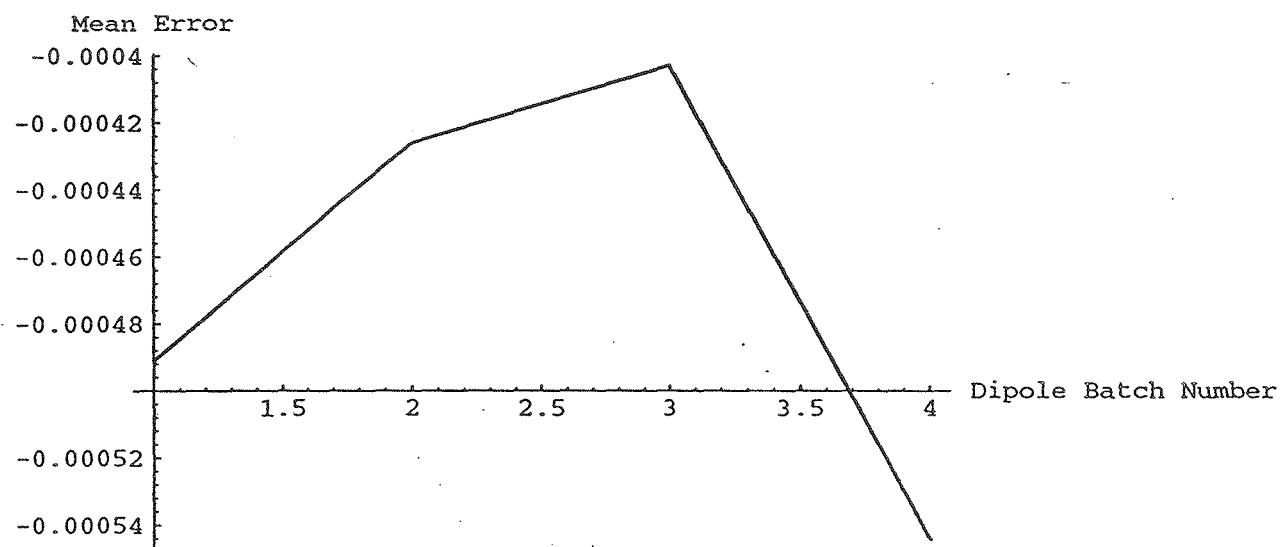


fig 1.

MEAN VALUE AS A FUNCTION
OF BATCH NUMBER

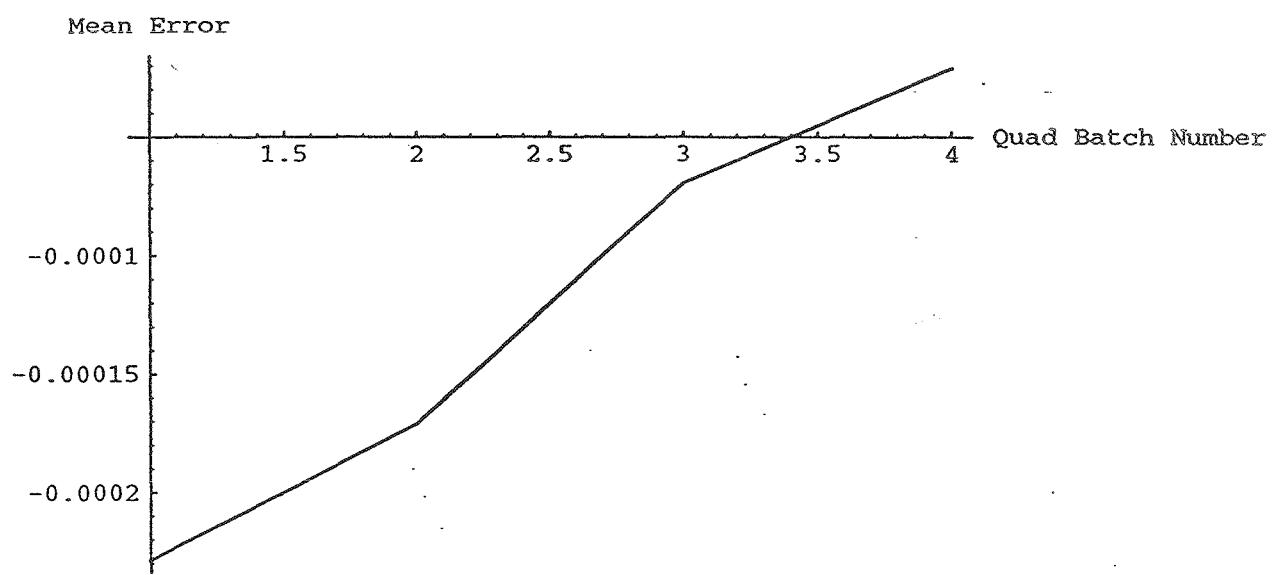


fig 2:

Table 2: SORTED BOOSTER QUARDRUPOLES:

Assigned Position	Quadrupole Name	Booster Position Name	Random Error Value
POSITION[1]	BQP022	B2C8QF	-0.0001060330120481927
POSITION[2]	BQP033	C7QD	-0.0003497130120481928
POSITION[3]	BQP021	QF	-0.0002422030120481927
POSITION[4]	BQP027	C6QD	-0.0002063730120481928
POSITION[5]	BQP019	QF	-0.0002135430120481927
POSITION[6]	BQP004	C5QD	-0.0002923730120481927
POSITION[7]	BQP009	QF	0.00003730698795180725
POSITION[8]	BQP020	C4QD	-0.0003783830120481928
POSITION[9]	BQP014	QF	-0.0001347030120481927
POSITION[10]	BQP017	C3QD	-0.0005002130120481928
POSITION[11]	BQP013	QF	-0.0002637130120481927
POSITION[12]	BQP008	C2QD	0.0001233069879518073
POSITION[13]	BQP012	QF	-0.0002278730120481928
POSITION[14]	BQP011	C1QD	-0.0005647230120481927
POSITION[15]	BQP010	QF	0.00003730698795180725
POSITION[16]	BQP006	C0QD	0.0004314869879518073
POSITION[17]	BQP025	QF	-0.0002063730120481928
POSITION[18]	BQP016	B1C9QD	0.0005246569879518073
POSITION[19]	BQP005	QF	0.000001466987951807253
POSITION[20]	BQP023	C8QD	-0.0006292230120481928

Assigned Position	Quadrupole Name	Booster Position Name	Random Error
			Value
POSITION[21]	BQP031	QF	0.0002594769879518072
POSITION[22]	BQP048	C7QD	-0.0001777030120481926
POSITION[23]	BQP026	QF	-0.0007295530120481928
POSITION[24]	BQP041	C6QD	0.0001376369879518072
POSITION[25]	BQP032	QF	-0.0007940630120481929
POSITION[26]	BQP038	C5QD	0.0002666469879518073
POSITION[27]	BQP053	QF	0.0004601469879518075
POSITION[28]	BQP030	C4QD	-0.0002852130120481928
POSITION[29]	BQP015	QF	0.0004099869879518073
POSITION[30]	BQP029	C3QD	0.00004446698795180727
POSITION[31]	BQP036	QF	-0.0005288830120481928
POSITION[32]	BQP054	C2QD	0.0001018069879518073
POSITION[33]	BQP037	QF	-0.0005002130120481928
POSITION[34]	BQP042	C1QD	-0.0002565430120481928
POSITION[35]	BQP039	QF	-0.0006793930120481928
POSITION[36]	BQP034	C0QD	0.0002308069879518072
POSITION[37]	BQP045	QF	0.0003598169879518073
POSITION[38]	BQP028	B4C9QD	0.0003454769879518072
POSITION[39]	BQP035	QF	0.0005246569879518073
POSITION[40]	BQP044	C8QD	0.0002594769879518072

Assigned Position	Quadrupole Name	Booster Position Name	Random Error Value
POSITION[41]	BQP024	QF	0.001004836987951807
POSITION[42]	BQP065	C7QD	0.0005533169879518073
POSITION[43]	BQP040	QF	-0.000980403012048193
POSITION[44]	BQP051	C6QD	0.0003239769879518072
POSITION[45]	BQP057	QF	0.0005748169879518074
POSITION[46]	BQP069	C5QD	0.0003454769879518072
POSITION[47]	BQP066	QF	0.0005819869879518074
POSITION[48]	BQP073	C4QD	0.0005461569879518074
POSITION[49]	BQP060	QF	0.000839996987951807
POSITION[50]	BQP052	C3QD	0.0001878069879518072
POSITION[51]	BQP043	QF	-0.0003927130120481928
POSITION[52]	BQP068	C2QD	0.0003239769879518072
POSITION[53]	BQP050	QF	0.0005891569879518073
POSITION[54]	BQP083	C1QD	0.0001304769879518072
POSITION[55]	BQP077	QF	0.0006751569879518074
POSITION[56]	BQP070	C0QD	0.00003730698795180725
POSITION[57]	BQP055	QF	-0.0004930530120481929
POSITION[58]	BQP063	B3C9QD	0.0002738069879518072
POSITION[59]	BQP082	QF	-0.0004428830120481928
POSITION[60]	BQP067	C8QD	0.00005880698795180727

Assigned Position	Quadrupole Name	Booster Position Name	Random Error Value
POSITION[61]	BQP018	QF	0.0007396569879518072
POSITION[62]	BQP080	C7QD	-0.00004870301204819274
POSITION[63]	BQP047	QF	0.0007683269879518074
POSITION[64]	BQP078	C6QD	0.0004171469879518073
POSITION[65]	BQP058	QF	-0.0001848730120481927
POSITION[66]	BQP059	C5QD	0.0000874669879518073
POSITION[67]	BQP061	QF	-0.000837063012048193
POSITION[68]	BQP071	C4QD	0.0006608269879518075
POSITION[69]	BQP075	QF	0.0007038269879518074
POSITION[70]	BQP007	C3QD	0.00007313698795180727
POSITION[71]	BQP079	QF	-0.0001562030120481928
POSITION[72]	BQP049	C2QD	0.0001233069879518073
POSITION[73]	BQP074	QF	0.0005461569879518074
POSITION[74]	BQP056	C1QD	0.0001663069879518072
POSITION[75]	BQP076	QF	-0.0001203730120481927
POSITION[76]	BQP072	C0QD	0.00005163698795180726
POSITION[77]	BQP081	QF	-0.0001418730120481928
POSITION[78]	BQP003	B2C9QD	0.0005031569879518073
POSITION[79]	BQP062	QF	-0.0006220530120481928
POSITION[80]	BQP064	C8QD	-0.000917030120481928